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International application number: PCT/CA05/000144

International filing date: 08 February 2005 (08.02.2005)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/542,297
Filing date: 09 February 2004 (09.02.2004)

Date of receipt at the International Bureau: 24 June 2005 (24.06.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

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PRIORITY APPLICATION NUMBER

(PCT Administrative Instructions,
Section 323(a), (b) and (c))

Applicant's or agent's file reference 115-39 PCT	Date of mailing *(day/month/year)*	17 June 2005 (17-06-2005)
International application No. PCT/CA2005/000144	International filing date *(day/month/year)*	08 February 2005 (08-02-2005)

Applicant
SIGE SEMICONDUCTOR INC. ET AL

1. [X]   This receiving Office hereby gives notice of the receipt of the priority document(s) identified below on:

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Identification of the priority document(s):

Priority date	Priority application No.	Country or regional Office or PCT receiving Office
09 February 2004 (09-02-2004)	60/ 542,297	US

Name and mailing address of the Receiving Office/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001(819)953-2476	Authorized Officer Terence Teoh (819) 997-6295

Form PCT/RO/135 (July 1998; reprint January 2004)

PA 1313827

CA05/144

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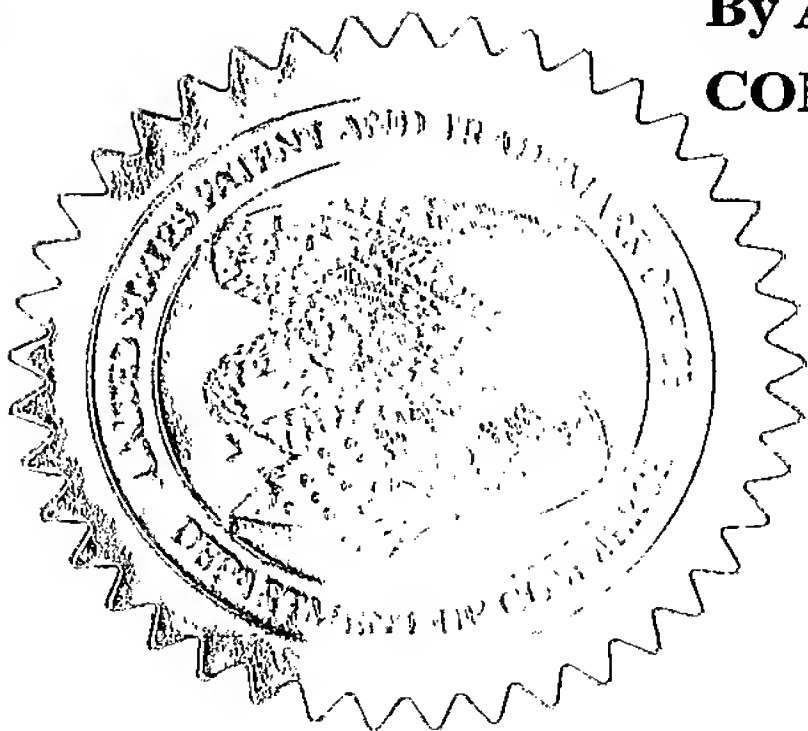
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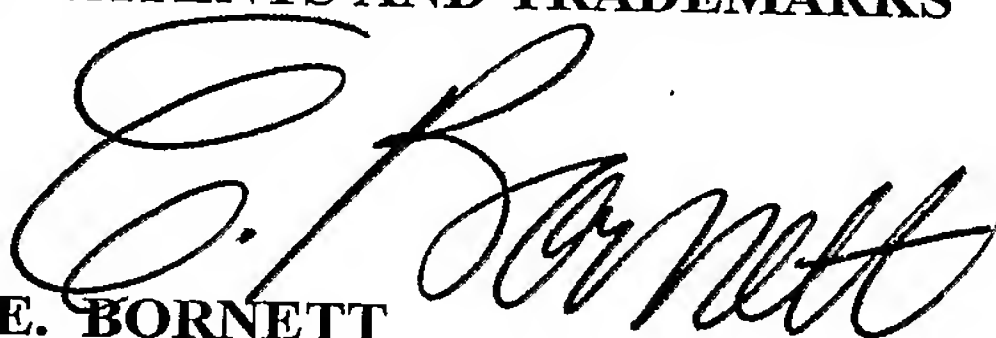
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APPLICATION NUMBER: *60/542,297*
FILING DATE: *February 09, 2004*

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

E. BORNETT
Certifying Officer

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPICATION FOR PATENT under 37 CFR 1.53(c).

INVENTOR(S)

	Given Name (first and middle [if any])	Family or Surname	Residence (City and either State or Foreign Country)
1	Martin Gordon	Jesson	Teversham, United Kingdom
2	Gareth	Bath	Ottawa, Ontario, Canada
3	Philip John	Macphail	Cambridge, United Kingdom
4			
5			

☐ Additional inventors are being named on the sheet attached hereto.

TITLE OF THE INVENTION (280 characters max)

Methods of Enhancing Power Amplifier Linearity

Direct all correspondence to:

CORRESPONDENCE ADDRESS

☒ **Customer Number 26,381**

Firm or Individual Name	Lacasse & Associates				
Address	1725 Duke Street				
Address	Suite 650				
City	Alexandria	State	VA	Postal Code	22314
Country	USA	Telephone	(703) 838-7683	Fax	(703) 838-7684

ENCLOSED APPLICATION PARTS (check all that apply)

☒	Specification	Number of pages:	11
☒	Drawing(s)	Number of Sheets:	2
☐	Other	Appendix A	

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☒	Applicant claims small entity status. See 37 CFR 1.27.		**FILING FEE AMOUNT (4)**
☒	The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number:	**50-1142**	**$80.00**

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.

☐ Yes, the name of the U.S. Government agency and the government contract number are:......................................

Respectfully submitted,

SIGNATURE: _(signature)_

DATE: February 9, 2004

TYPED or PRINTED NAME: Randy W. Lacasse
REGISTRATION NO.: 34,368
TELEPHONE: (703) 838-7683

DOCKET NO: 115-39 US Prov
FAX: (703) 838-7684

Methods of Enhancing Power Amplifier Linearity

Field of the Invention

[001]   The invention relates to the field of RF transmitter circuits and more specifically to the field of RF transmitter circuits that employ a predistorter circuit.

Background of the Invention

[002]   Modern digital wireless communication systems use complex modulation schemes in order to provide data between a transmitter and a receiver at high data rates using a modulated wireless signal within a limited spectral bandwidth.

[003]   These modulated signals tend to have high peak-to-mean power ratios and require highly linear amplification. One example of such modulation is the OFDM that is used in a wireless LAN standard 802.11g, as is well known to those of skill in the art. These modulation schemes require high modulation accuracy due to a number of bits of information coded onto each carrier signal.

[004]   Power amplifiers (PAs) are utilized in a majority of wireless LAN transmitters. These transmitters operate with a mean output signal power that is much lower than a 1dB compression point of the PA. The difference between the mean output signal power and the 1dB compression point of the amplifier is often called linearity back-off. Clearly, it is a design objective to determine a degree of the linearity back-off relative to a required linearity. This determination of degree is necessary to provide adequate linearity for the PA.

[005]   An algorithm for the adaptation of the pre-distortion values is described in the following conference paper: K Wesolowski and J Pochmara, "Efficient Algorithm for Adjustment of Adaptive Predistorter in a Transmitter for OFDM Signals", IEEE Vehicular Technology Conference, Fall 2000.

[006]   It is well understood to those skilled in the art of PA design that operating a RF power amplifier at a power much lower than its maximum capability reduces the

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efficiency of conversion of DC power to RF power. Moreover, the linearity back-off becomes a larger disadvantage, due to a larger efficiency impact, as the RF power requirement increases. In addition, it becomes more difficult to realize such a PA with the required performance using low cost technology.

[007] The objective of the present invention is to improve the performance of a transmitter system that utilizes a conventional PA of moderate linearity so that it meets modulation requirements in accordance with predetermined modulation schemes and with low cost and low power consumption.

Summary of the Invention

[008] In accordance with the invention there is provided a method of transmitting a RF signal comprising: providing of a lookup table (LUT) for storing of predistortion data; providing a power amplifier circuit for receiving a first analog RF signal and for providing the RF signal therefrom; receiving of a digital modulated signal; indexing of the LUT to provide indexed predistortion data; predistorting the digital modulated signal in dependence upon the indexed predistortion data to form a predistorted digital modulated signal; converting the predistorted digital modulated signal into an analog modulated signal; amplifying the analog modulated signal using the power amplifier to form the RF signal; sampling a portion of the RF signal; and, varying the index within the LUT for other than continuously changing the predistortion data that is used for predistorting of the digital modulated signal in dependence upon the sampled RF signal.

Brief Description of the Drawings

[009] Exemplary embodiments of the invention will now be described in conjunction with the following drawings, in which:

[0010] FIG. 1 illustrates an envelope based adaptation of a transmitter circuit; and,

[0011] FIG. 2 illustrates a quadrature based adaptation of a transmitter circuit.

[0012] FIG. 3 illustrates a method steps in operating of a transmitter circuit, such as that illustrated in FIGs 1 and 2.

Detailed Description of Embodiments of the Invention

[0013] FIG. 1 illustrates a portion of a transmitter system 100 having an input port 100a for receiving a digital modulated signal and having an output port 100b for providing a radio frequency (RF) signal therefrom. A digital predistorter circuit 101 has an input port coupled to port 100a for receiving the digital modulated signal and for providing a predistorted digital modulated signal from an output port thereof. Disposed within the digital predistorter circuit 101 is a lookup table (LUT) 110 for storing of predistortion data. Coupled to an output port of the digital predistorter circuit 101 is a digital to analog converter (DAC) 103 for converting the predistorted digital modulated signal to an analog representation thereof. A RF modulator 103 receives this analog representation and modulates this signal to form a modulated signal that is provided to an input port of a power amplifier (PA) 104 circuit. The PA 104 amplifies the modulated signal and provides it to the output port 100b of the transmitter 100. An envelope detector 105 is coupled to the PA 104 for receiving a portion of the amplified modulated signal and for providing this signal to an analog to digital converter (ADC) 106. The ADC converts the portion of the amplified modulated signal into a digital representation thereof for provision to an adaptation control circuit 107, which is then coupled to the predistortion circuit 101 for, at least in part, controlling the operation thereof using a control signal.

[0014] The control signal is used to index the LUT 210 for selecting of predistortion data stored therein for use by the predistorter circuit 101 in predistorting of the digital modulated input signal.

[0015] In operation of the transmitter 100, the input signal to the PA 104 is predistorted using the predistortion circuit 101 by accessing stored values within the LUT 110 in the digital domain. The input signal that is represented in a digital format is adjusted by the parameters in the look-up table to form an alternative input signal that is downstream provide to the PA 104 that compensates for the expected non-linearities of the PA 104 and optionally other components in the signal path. This technique of adjusting the input signal while it is still in a digital format takes advantage of the continuing decrease in size

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and cost of digital circuits. It is also preferable to adapt the values stored in the LUT 110 to compensate for variations in the performance of the RF PA 104 for external conditions, such as changes in temperature, supply voltage or output load.

[0016] For the transmitter circuit shown in FIG. 1, the varying of predistortion parameters based upon the control signal is dependent upon the amplitude of the transmitted signal alone, where this sampling of the amplitude of the transmitted signal alone is performed in conjunction with the high-speed envelope detector 105.

[0017] FIG. 2 illustrates a preferred embodiment of the invention, a portion of a transmitter circuit 200 that is a variation of the portion of the transmitter circuit 100 shown in prior art FIG. 1. An input port 200a is provided for receiving a digital modulated signal and an output port 200b is provided for emitting a RF signal therefrom. A digital predistorter circuit 201 has an input port coupled to input port 200a for receiving the digital modulated signal and for providing a predistorted digital modulated signal from an output port thereof. Disposed within the digital predistorter circuit 201 is a lookup table (LUT) 210 for storing of predistortion data. Coupled to an output port of the digital predistorter circuit 201 is a digital to analog converter (DAC) 203 for converting the predistorted digital modulated signal to an analog representation thereof. A RF modulator 203 receives this analog representation and modulates this signal to form a modulated signal that is provide to an input port of a power amplifier (PA) 204 circuit. The PA 204 amplifies the modulated signal and provides it to the output port 200b of the transmitter 200. An attenuator 211 is disposed between an input port 220a of an existing receiver circuit 220 and the output port 200b. The existing receiver circuit includes a low noise amplifier (LNA) circuit 209, a RF demodulator circuit 208, a first ADC 206a and a second ADC 206b. Output ports of the two ADCs form first and second output ports, 220b and 220c, of the existing receiver circuit 220.

[0018] The LNA 209 receives a portion of the RF output signal power through the attenuator 211 and provides an amplified version thereof to the RF demodulator circuit 208, in the form of a quadrature down-conversion mixer for providing first and second

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demodulated signals, 'I' and 'Q' signals, respectively, therefrom. Each of these demodulated signals is then converted to the digital domain using the first and second ADCs 206a and 206b. An adaptation control circuit 207 is provided external to the existing receiver circuit 220 for receiving of the digitally represented demodulated signals. The adaptation control circuit 207 is coupled to the predistortion circuit 201 for, at least in part, controlling the operation thereof using a control signal. The control signal is used to index the LUT 210 for selecting of predistortion data stored therein for use by the predistorter circuit 201 in predistorting of the digital modulated input signal.

[0019] In the preferred embodiment, both amplitude and phase of the RF output signal are sampled using the existing receiver circuit 220. Preferably, the quadrature down-conversion mixer utilizes circuitry of an existing wireless local area network (WLAN) receiver in order to reduce electrical component costs.

[0020] For determining optimal predistortion data for the transmitter circuit 100, 200, a predetermined symbol pattern is provided concurrently with the digital modulated signal at a same carrier frequency. The existing receiver circuitry 220, or detector circuit 105, samples the RF output signal that includes a variation of the predetermined symbol pattern. The variation of the predetermined symbol pattern is dependent upon the transmitter circuit distortion during signal propagation from the input port 100a, 200a to the output port 100b, 200b thereof. A comparison is performed between the predetermined symbol pattern and the variation of the predetermined symbol pattern and in dependence upon this comparison the control signal provided from the adaptation control circuit 107, 207 is varied in order to change an index within the LUT 110, 210 that is used for indexing of the predistortion data stored therein. The index of the LUT 110, 210 is varied until a difference between the predetermined symbol pattern and the variation of the predetermined symbol pattern is preferably minimized. Preferably the predetermined symbol pattern is graphically represented by a sinewave.

[0021] In both embodiments, the digital circuits sample a portion of transmitted RF signal. This portion preferably contains the part of the transmitted RF signal with largest

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amplitude components, typically the part containing user data, and at times the variation of the predetermined symbol pattern at the carrier frequency. The digital circuits construct an ideal transmit signal due to the sampled transmitted RF signal and take into account any pulse shaping or reconstruction filters that are disposed in the signal path leading up to the RF power amplifier. This ideal signal is compared with samples of the sampled actual predetermined symbol pattern transmitted and the error is computed. For this computation, a precise time alignment of the two signals is implemented, which is the predetermined symbol pattern and the sampled predetermined symbol pattern. Preferably the time alignment is achieved by a correlation or error minimization technique and may use predetermined values based on prior knowledge of the analog circuits. Once the time difference is found, a slow, and preferably other than continuous variation of indexing of entries of predistortion data within the LUT takes place.

[0022] The computed error in the transmitted RF signal and knowledge of the ideal signal at the same instant in time are used to vary the indexing of the predistortion data that is stored in the LUT. In the case of amplitude detection only, sampling of the transmitted RF signal results in the index to the LUT 110 for indexing predistortion data relating to, for example, modification of magnitude for the predistorted signal. Optionally, predistortion data for both magnitude and phase are varied when a relationship between the magnitude and phase response of the RF power amplifier is known. Any such relationship is preferably pre-programmed into the adaptation control circuit, 107 or 207, prior to operation of the transmitter circuit, 100 or 200. In the preferred embodiment, when both amplitude and phase information are available, due to quadrature sampling of the transmitted RF signal, then magnitude and phase corrections are determinable without further information requirement about the PA 204.

[0023] Initial values are provided in the LUT at start-up of the transmitter circuit 100, 200 based upon known characteristics of the PA, 100 or 200, and in testing of the PA for various environmental factors. This LUT 110 is either in then in the form of a single index LUT, where for example only magnitude information about the sampled signal is used for indexing of the LUT, or if an envelope detector is used, as in the preferred

embodiment of FIG. 2, and adaptation of phase correction is to be performed, then indexing predistortion data for attaining both amplitude and phase correction is performed in the LUT 210.

[0024] In operation each complex base-band value to be transmitted is preferably multiplied by an interpolated value derived from the LUT 200 before being provided to the pulse-shaping filter, which is either an analog or digital circuit. Small values of amplification do not require correction because common PAs are sufficiently linear at low power output levels. When an envelope detector is used to provide feedback, such as that illustrated in FIG. 1, such detectors have a limited dynamic range; however, since at low amplification no correction is required it is advantageous to focus the reduced dynamic range to regions of higher amplification in order to provide correction therefor.

[0025] The detected transmitted signal is supplied to the base-band as envelope only or in quadrature form. This is used to modify the look-up table to minimize the error in the transmitted signal using a pre-programmed algorithm.

[0026] FIG. 3 summarizes the steps of operation for the transmitter circuits illustrated in FIGs. 1 and 2. A method of transmitting a RF signal comprising: providing of a lookup table (LUT) for storing of predistortion data; providing a power amplifier circuit for receiving a first analog RF signal and for providing the RF signal therefrom; receiving of a digital modulated signal; indexing of the LUT to provide indexed predistortion data; predistorting the digital modulated signal in dependence upon the indexed predistortion data to form a predistorted digital modulated signal; converting the predistorted digital modulated signal into an analog modulated signal; amplifying the analog modulated signal using the power amplifier to form the RF signal; sampling a portion of the RF signal; and, varying the index within the LUT for other than continuously changing the predistortion data that is used for predistorting of the digital modulated signal in dependence upon the sampled RF signal.

[0027] Prior art systems for pre-distorting RF signals prior to the power amplifier are available. However these prior art systems operate independently and require significant additional circuitry that render them unsuitable for use in low power wireless transmitters. The embodiments of the present invention advantageously combine pre-distortion with existing base-band processing circuitry and advantageously reuse existing receiver circuitry, thereby providing for reduced additional component cost over available prior art systems.

[0028] It will be apparent to a person of skill in the art that the predistorter is optionally capable of modifying its response in order to enhance performance. In a WLAN application the packet starts with a comb of pilot tones that have characteristics of a pulse. Processing the pilot tones provides coefficients for the look-up table. Another option is to begin transmitting a signal at low power and gradually increase the signal intensity as corrections are calculated.

[0029] Numerous other embodiments may be envisaged without departing from the spirit or scope of the invention.
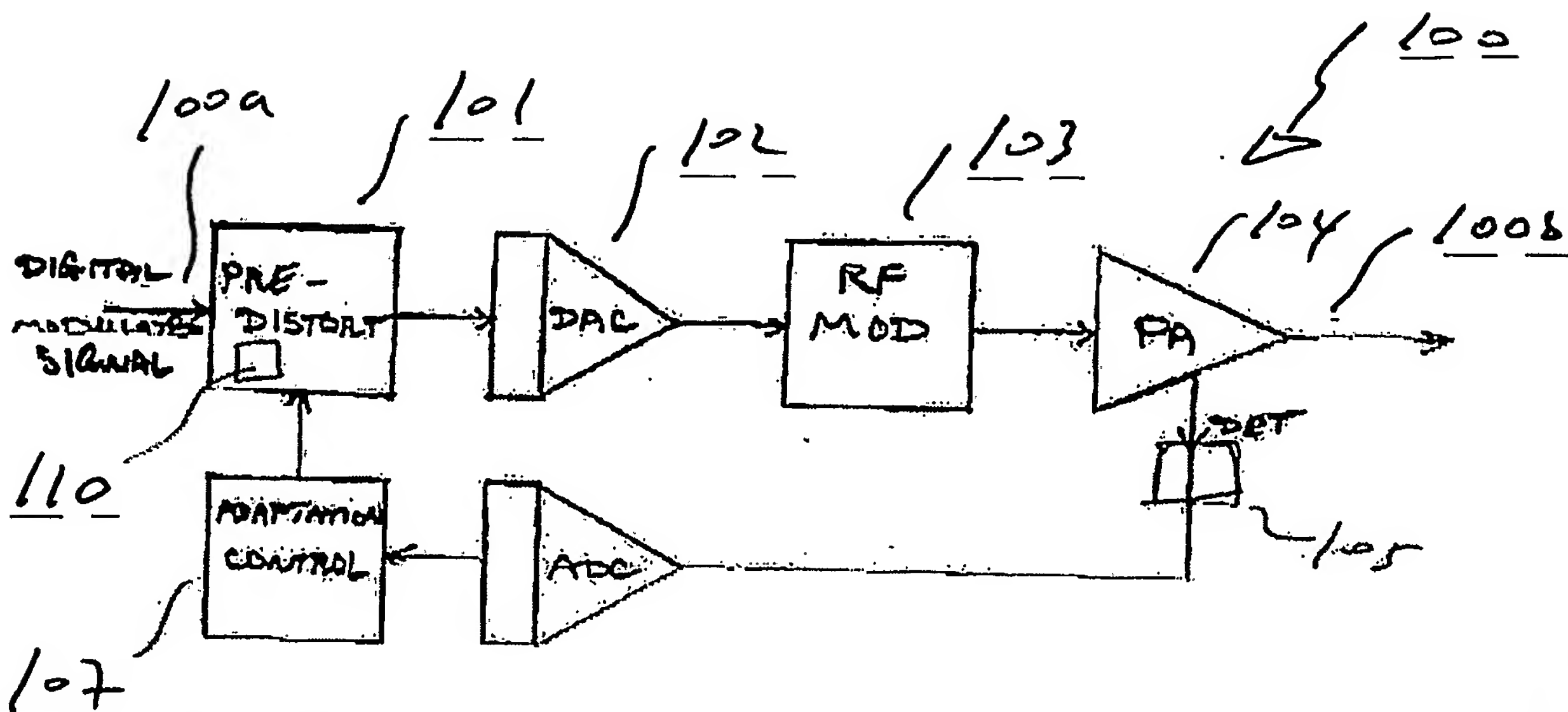
Claims

What is claimed is:

1. A method of transmitting a RF signal comprising:

providing of a lookup table (LUT) for storing of predistortion data;

providing a power amplifier circuit for receiving a first analog RF signal and for providing the RF signal therefrom;

receiving of a digital modulated signal;

indexing of the LUT to provide indexed predistortion data;

predistorting the digital modulated signal in dependence upon the indexed predistortion data to form a predistorted digital modulated signal;

converting the predistorted digital modulated signal into an analog modulated signal;

amplifying the analog modulated signal using the power amplifier to form the RF signal;

sampling a portion of the RF signal; and,

varying the index within the LUT for other than continuously changing the predistortion data that is used for predistorting of the digital modulated signal in dependence upon the sampled RF signal.

2. A method according to claim 1 comprising:

providing a digital signal having a first predetermined symbol pattern concurrently with the digital modulated signal;

sampling a portion of the RF signal;

extracting a second predetermined symbol pattern from the RF signal;

comparing the second predetermined symbol pattern to the first predetermined symbol pattern; and,

varying the index within the LUT in dependence the comparison.

3. A method according to claim 1 wherein the index for the LUT is varied in dependence upon at least one of a temperature of the power amplifier and supply voltage and output load.

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4. A method according to claim 1 wherein sampling the portion of the RF signal comprises:

providing an amplitude detector with a predetermined dynamic range; and,

focusing the predetermined dynamic range of the detector to detect within higher amplitudes of the RF signal in order to provide the sampling for varying the index within the LUT.
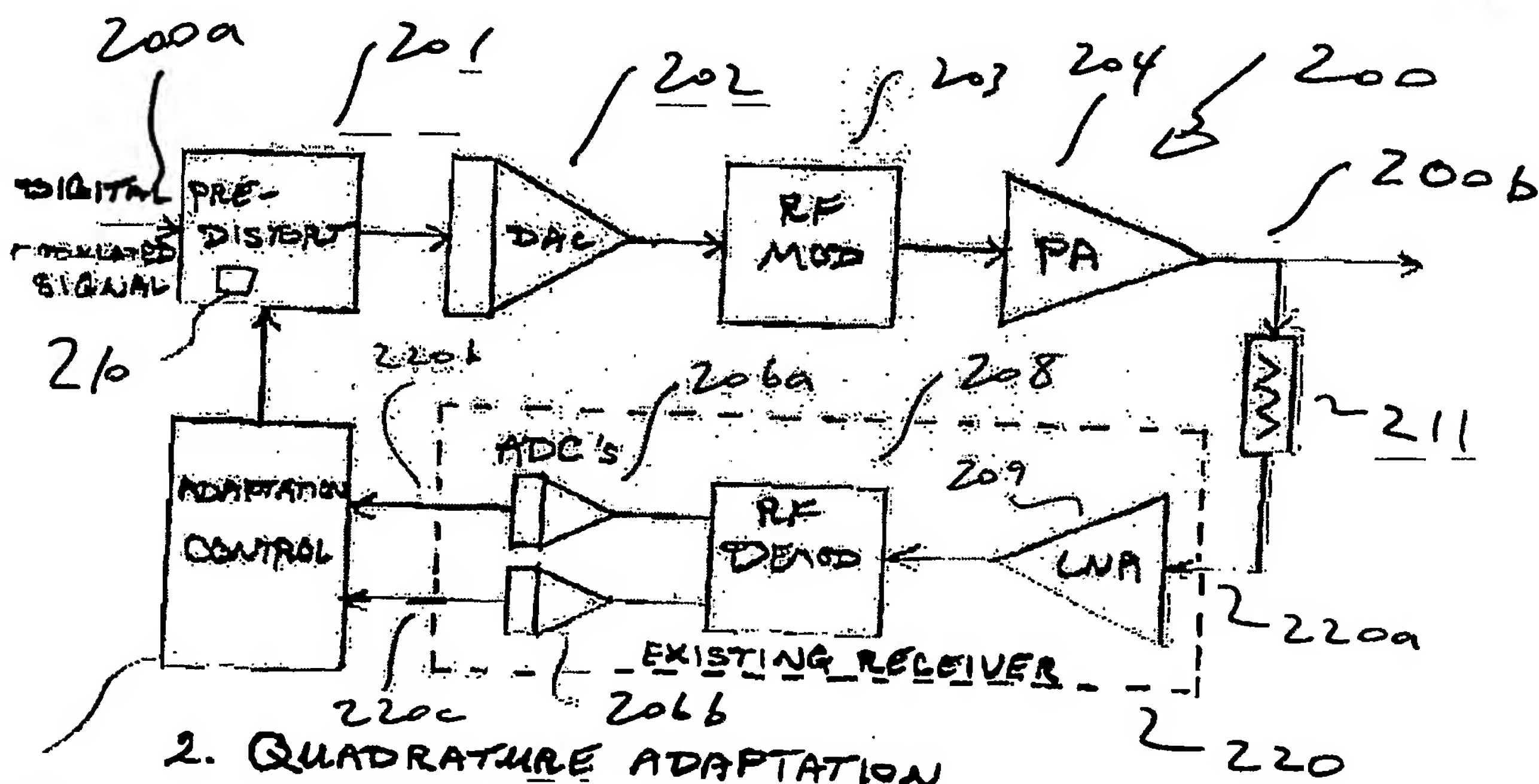
Abstract

A novel method of enhancing power amplifier linearity is disclosed.

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1. ENVELOPE BASED ADAPTATION   FIG. 1

2. QUADRATURE ADAPTATION

FIG. 2

providing of a lookup table (LUT) for storing of predistortion data;

providing a power amplifier circuit for receiving a first analog RF signal and for providing the RF signal therefrom;

receiving of a digital modulated signal;

indexing of the LUT to provide indexed predistortion data;

predistorting the digital modulated signal in dependence upon the indexed predistortion data to form a predistorted digital modulated signal;

converting the predistorted digital modulated signal into an analog modulated signal; amplifying the analog modulated signal using the power amplifier to form the RF signal; sampling a portion of the RF signal;

varying the index within the LUT for other than continuously changing the predistortion data that is used for predistorting of the digital modulated signal in dependence upon the sampled RF signal.

FIG.3